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ADTEC

Sixth Quarterly Report

STUDY PROGRAM ON (30-100 GHz) ELECTRONICALLY STEERABLE ANTENNA SYSTEMS

20 October 1967 - 20 January 1968

Contract NAS 5-10256

Prepared for

Applications Experiments Branch
Goddard Space Flight Center
Greenbelt, Maryland

ADVANCED TECHNOLOGY CORPORATION

1830 YORK ROAD TIMONIUM, MARYLAND

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Prepared by

John M. Cotton, Jr.
and
Dennis E. Grimes

ADVANCED TECHNOLOGY CORPORATION
1830 York Road
Timonium, Maryland
21093

for

Applications Experiments Branch
Goddard Space Flight Center
Greenbelt, Maryland

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1. INTRODUCTION

The five previous quarterly reports on this program have summarized studies made to determine optimum phased array techniques for use at millimeter wavelengths. The specific application is to be a satellite borne electronically steerable antenna. After a comprehensive survey of available techniques, the study continued with an elimination process which reduced the number of recommended approaches to six. Five of these six employ phase shifting the r.f. either at the transmitting frequency, or at the sub-harmonic, while the last uses retrodirective techniques accomplishing the phase shifting at IF.

Three of the six were selected for further study including actual design and experimental devellpment of a feasibility model at 35 GHz. These three have a common radiating aperture -- an array which remains filled, but in the light of the limited steering requirements can employ a smaller number of higher gain elements.

This report summarizes the results of the experimental work done in this quarter on various aspects of the antenna system. Utilizing the data accumulated from previous experimental work, three of the series feed arms to be employed in the feasibility model were fabricated and preliminary tests have been completed. In addition to this, work has also been done on the design and fabrication of a phase corrected optical feed system.

2. SERIES FEED SYSTEM

The envisioned antenna, a 49 element array with a series feed system is depicted in Figure 1. Power division is accomplished through the use of eight, seven port couplers employing broadwall slots to achieve the coupling as has been previously reported.

Three such seven port couplers have been fabricated and the proper slot size at each port determined to produce a cosine on a pedestal power distribution. One of these sections is shown in Figure 2 and schematically in Figure 3. The completed sections have a greater transmission loss than the .62 dB which was hoped for, but none have a loss which exceeds .85 dB.

Loss was a problem which continually hampered the development. Some of the major causes were leakage at the joint between shims and waveguide walls; wobble in the tuning screws; incorrectly seated shims. These problems have all been corrected by improved fabrication techniques. The extent of the machining tolerances necessary to prevent leakage loss is illustrated by the wobble in the tuning screws. The holes for these screws were only .0015 inches larger than the diameter of the screws yet this allowed enough wobble that tuning problems and loss were encountered.

2.1 Method Tuning the Series Feed Section

Since the tuning technique differed somewhat from that which was originally intended both methods will be detailed below.

2.1.1 Original concept of Tuning

Each series feed section contains seven ports three of which are shown in Figure 4. In the original concept of the development process, it was assumed that each port slot size could be considered more or less independently. This being the case, a shim with approximately the right size slot would be put in port n + 1 while all previous ports are closed and all succeeding ports remain

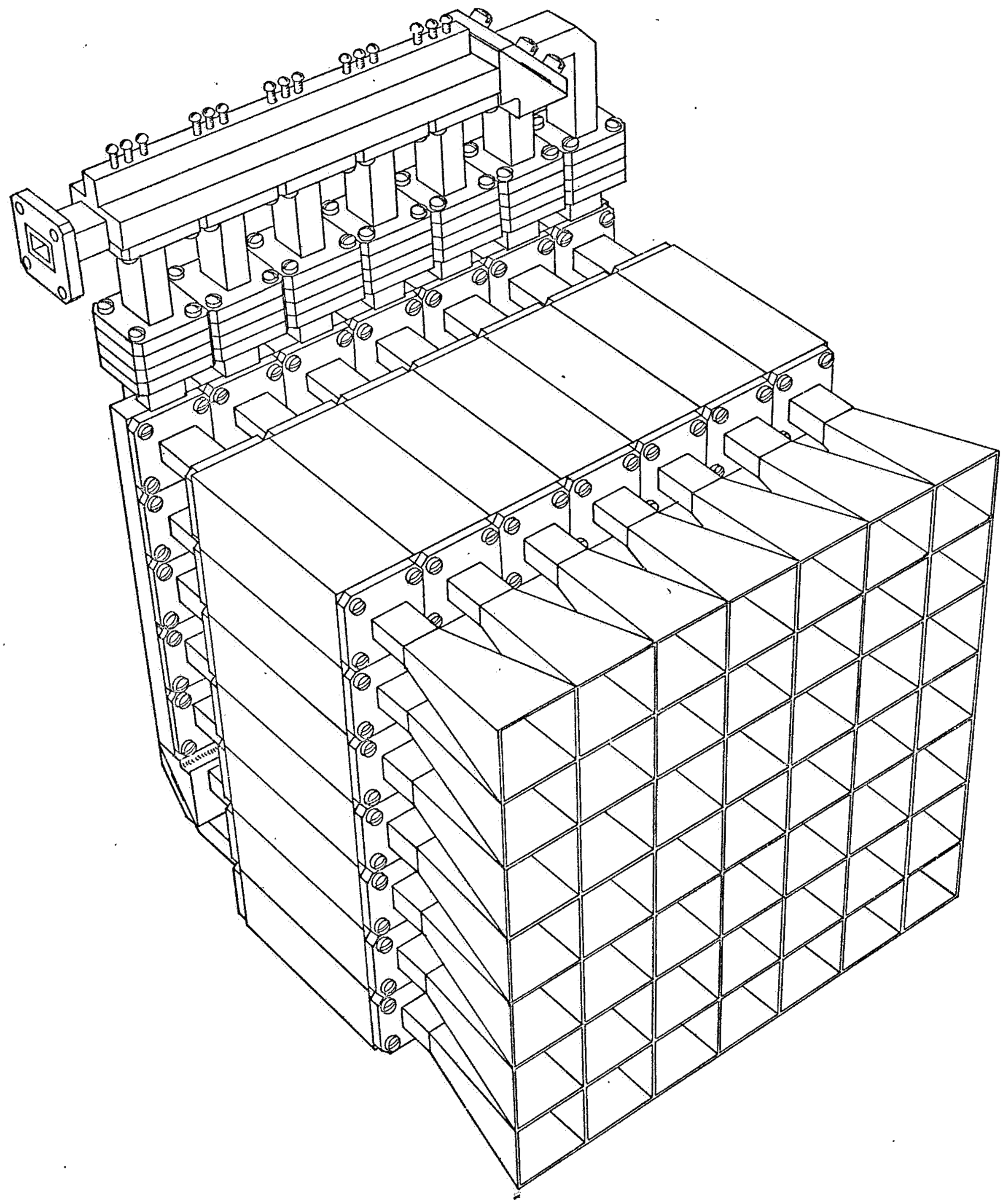

FIG. 1 - FEASIBILITY MODEL OF ARRAY USING A CORPORATE FEED

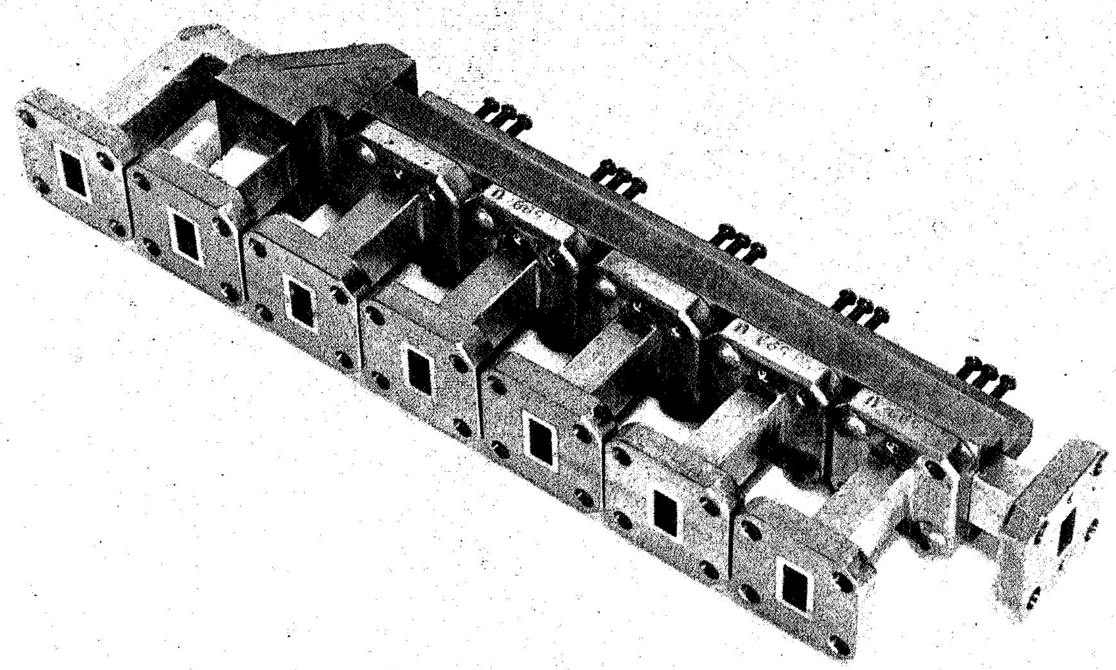

FIG. 2 - ASSEMBLED SERIES COUPLER FEED

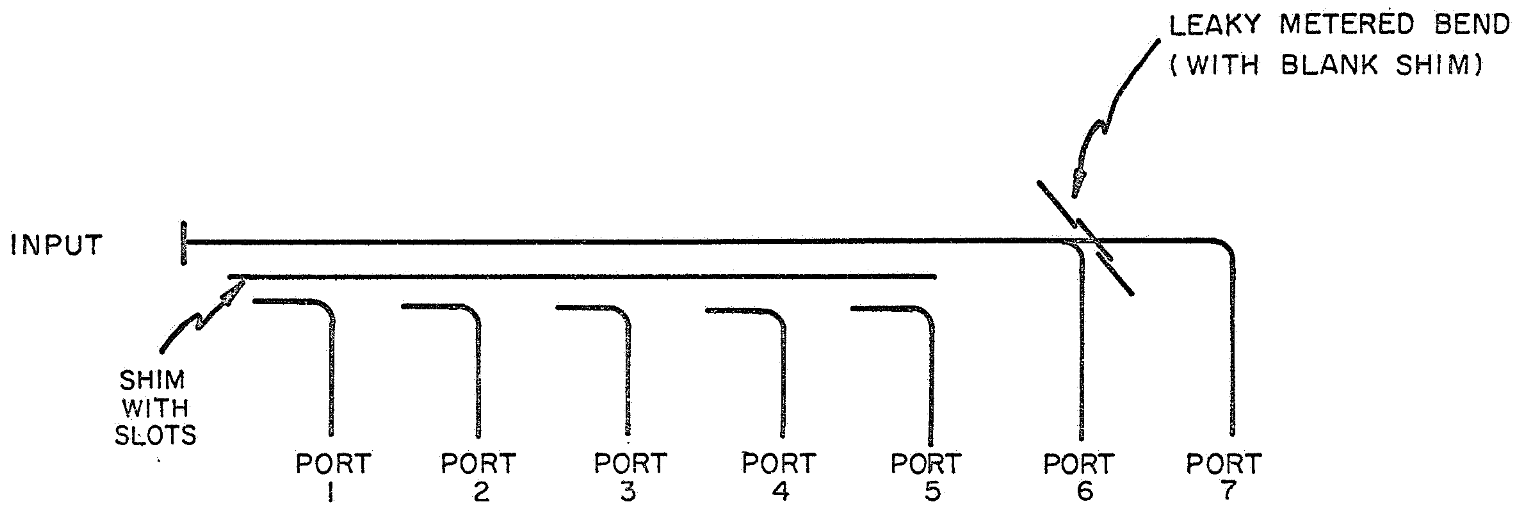

FIG.3-SCHEMATIC OF SERIES FEED SECTION

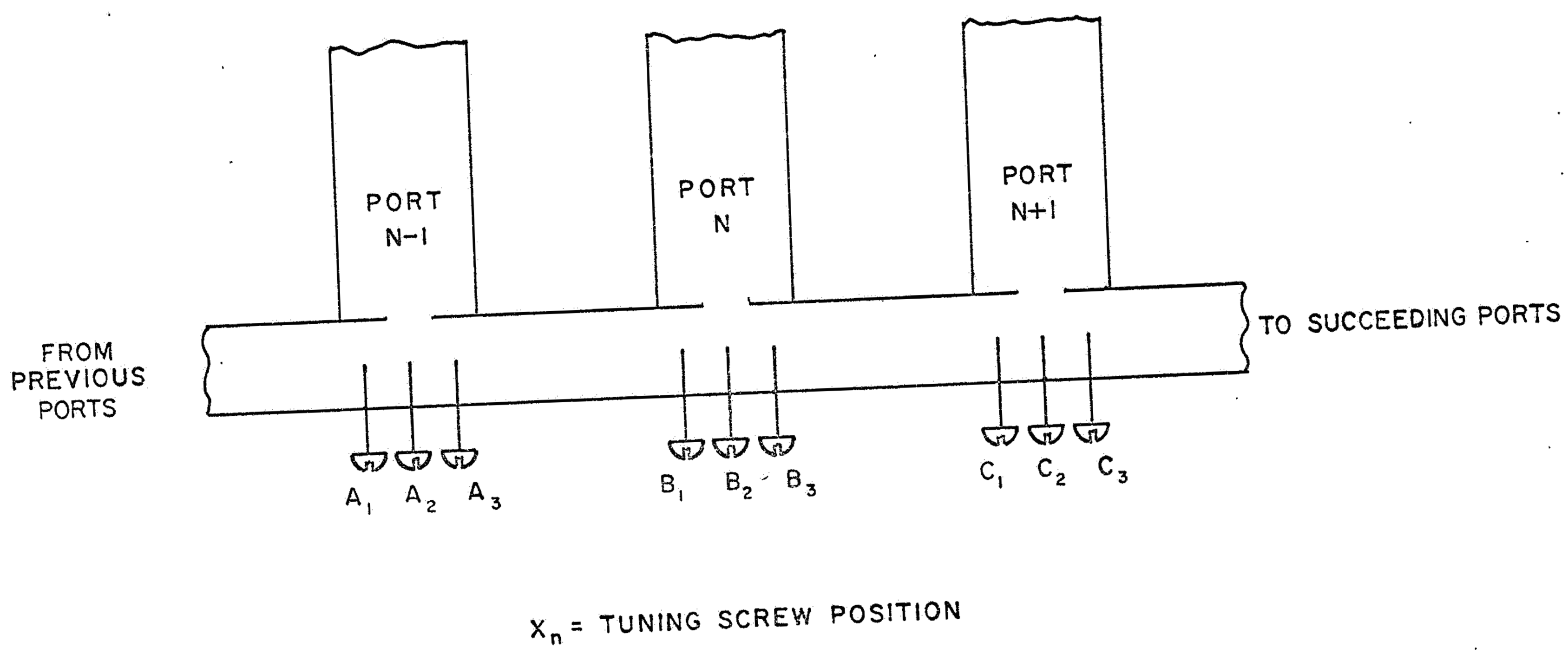

FIG. 4 -TYPICAL CONFIGURATION OF PORTS AND TUNING SCREWS

unchanged. The length of the slot at port n + 1 would be varied until the correct coupling was achieved; then matched to the input with the three tuning screws available at that port. The shim would then be left in port n + 1 and process repeated for port n. The procedure would continue until each of all seven ports had its own shim with the proper slot size. However, due to leakage from gaps between shims and mutual coupling between ports, this method is impractical.

2.1.2 Technique of Variable Tuning

Since the cure for leakage between shims is to put all slots in a common shim, some mechanism was necessary to enable small corrections to be made in coupled power to allow for changes in slot size due to machining tolerances. A technique was developed by which small changes could be effected at port n + 1 by varying the insertion of C_3 while maintaining a match with C_1 and C_2. In fact, once approximately correct power levels were achieved at all seven ports, a limited amount of trimming could be performed (using only the third screw, i.e. A_3, B_3, C_3, etc.) at any port without greatly affecting either the match or the transmission loss.

This technique was extremely useful in the development of the three feed sections.

3. OPTICAL FEED

A parallel development to the series feed system employs a quasi-optical distribution system. This will involve the use of a large illuminating aperture and a 49 element collecting array. Some of the fabrication and analysis of this approach has been completed in this period.

3.1 Lensed Illuminating Horn

The envisioned quasi-optical feed system is illustrated in Figure 5. The large horn radiates power directly into an array of collecting horns which bring the energy back into standard wave-

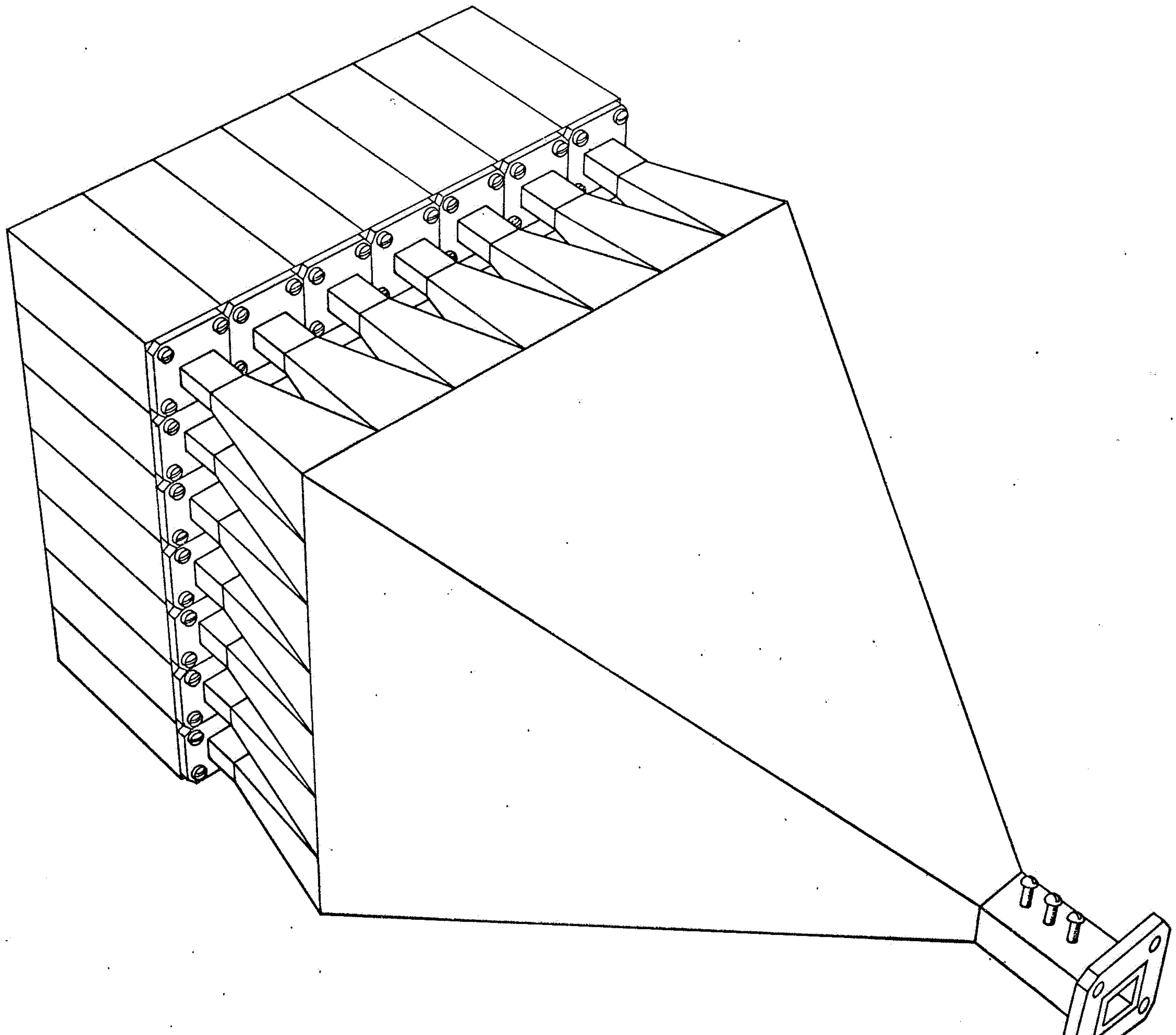

FIG. 5 - FEASIBILITY MODEL OF OPTICAL FEED

guide for the phase shifting operation. From there it is fed into a uniform output array of horns and radiated, steered in a direction determined by the amount of phase shift each element has undergone.

The large optical horn has an output with an inherent phase deviation across the aperture, of which the maximum is at the center. It was previously reported that this difference was 0.32λ but subsequent calculations reveal it to be about 1.3λ. The equi-phase contour, then is approximately spherical (for horn flare angles of less than 60°) with a 1.3λ difference in phase from center to edge. Since the equi-phase contour of the optical horn is not the complement of that of each of the small collecting horns, a "field" mismatch occurs at each of the collecting horns. The mismatch is not constant over the aperture of the uncorrected optical feed horn. Therefore a lens has been designed and manufactured which, in theory, will transform the spherical phase front into a plane one. This correction should produce a uniform field mismatch at each element across the collecting array. The power variation across the lens was calculated based on the use of one of the uniform output array horns as a probe and assuming no field mismatch between the two horns. Figure 6 is an exploded view of the lensed horn.

Using one such horn as a probe, the power distribution across the aperture was measured with and without the lens in position. Data from these preliminary tests revealed certain discrepancies from the predicted values. In the H-plane, where the power variation was calculated to be about 12 dB (ratio of power intercepted by edge and center horns), a 16 dB variation was discovered. In the E-plane, where there should be no variation, a 7 dB taper was recorded. In an effort to gain more information a finer probe was used, i.e. an open-ended waveguide, and the density of readings increased. This method led to a recording of only a 1.5 dB variation in the E-plane.

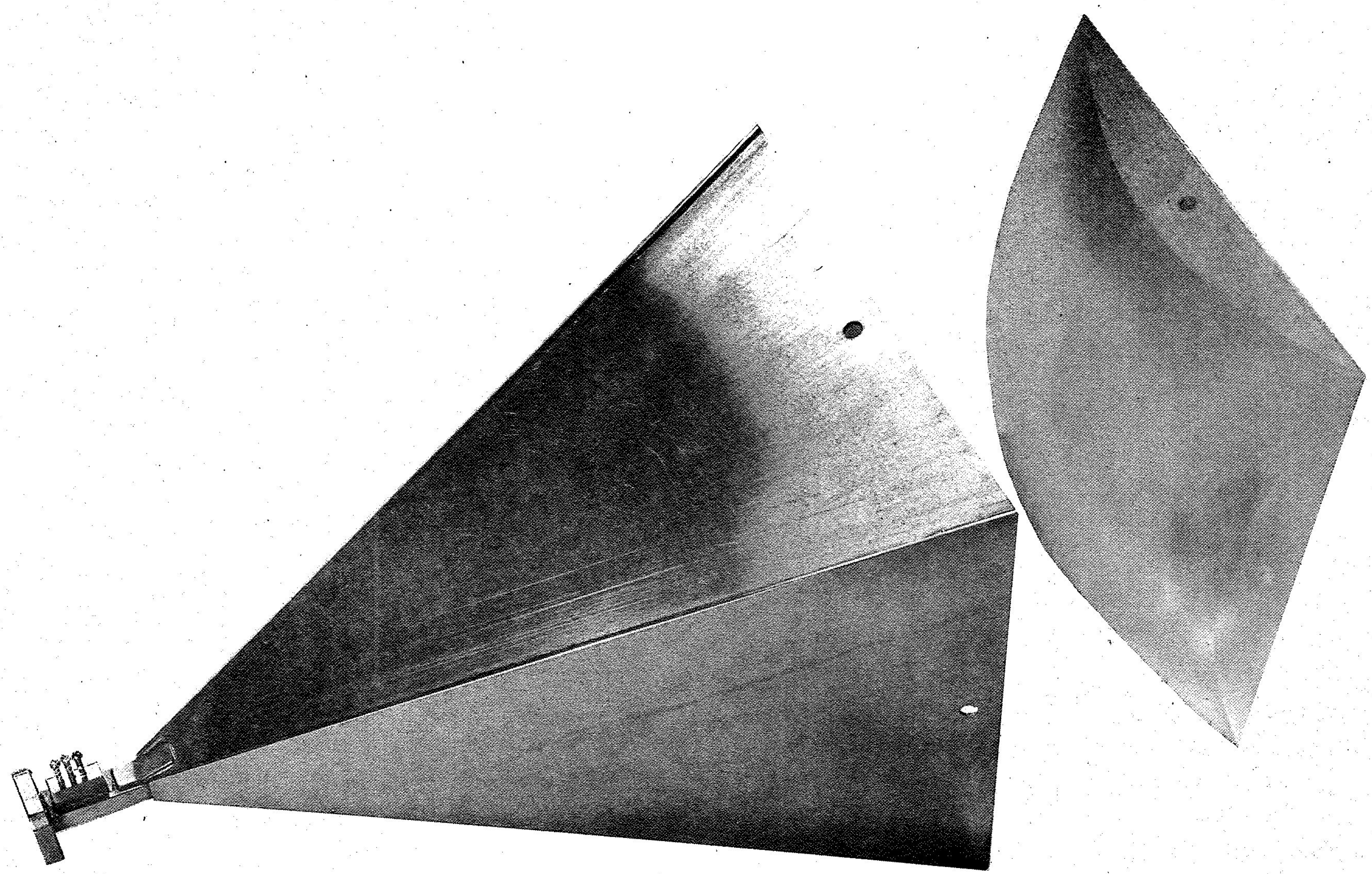

FIG. 6 - EXPLODED VIEW OF LENSED HORN

The H-plane measurements indicated a closer approximation to a cosine taper which corresponds to the theory, i. e., with an infinitely small probe, the power should approach zero at the walls of the horn, hence a larger taper, and follow a cosine power distribution across the aperture. The data verified this with a measured taper of 20 dB from center to edge. Figures 7 and 8 are E-plane samplings, using the open-ended waveguide as a probe, with and without the lens in the aperture of the optical horn. Similarly Figures 9 and 10 are H-plane samplings.

Amplitude measurements made were inconclusive. The erratic power variations incurred indicated that either the lens was not focusing correctly, or that multiple reflections off the surfaces of the lens were producing distorted patterns. A combination of both of these effects is also a possibility. Some phase measurements were made and a typical set of data is illustrated in Figure 11 which is an E-plane cut. It was clear at this point that the lens was not focusing properly. It has since been redesigned and fabricated and is now being tested.

In the event that multiple reflections are the cause of the discrepancies encountered, two techniques are being investigated to correct the situation. Since the reflections are caused by a mismatch between transmission media, an investigation of its extent and possible cures for the structure concerned is in order.

The mere fact that the impinging energy encounters an air-dielectric interface, accounts for a certain loss due to reflection. For the case in question and assuming only normal incidence, this loss amounts to about .46 dB for both surfaces of the lens. This represents an average figure. In actuality the power reflection coefficient varies from .231 at the center of the lens (normal incidence) to nearly zero at the corner of the horn (i. e., largest angle of

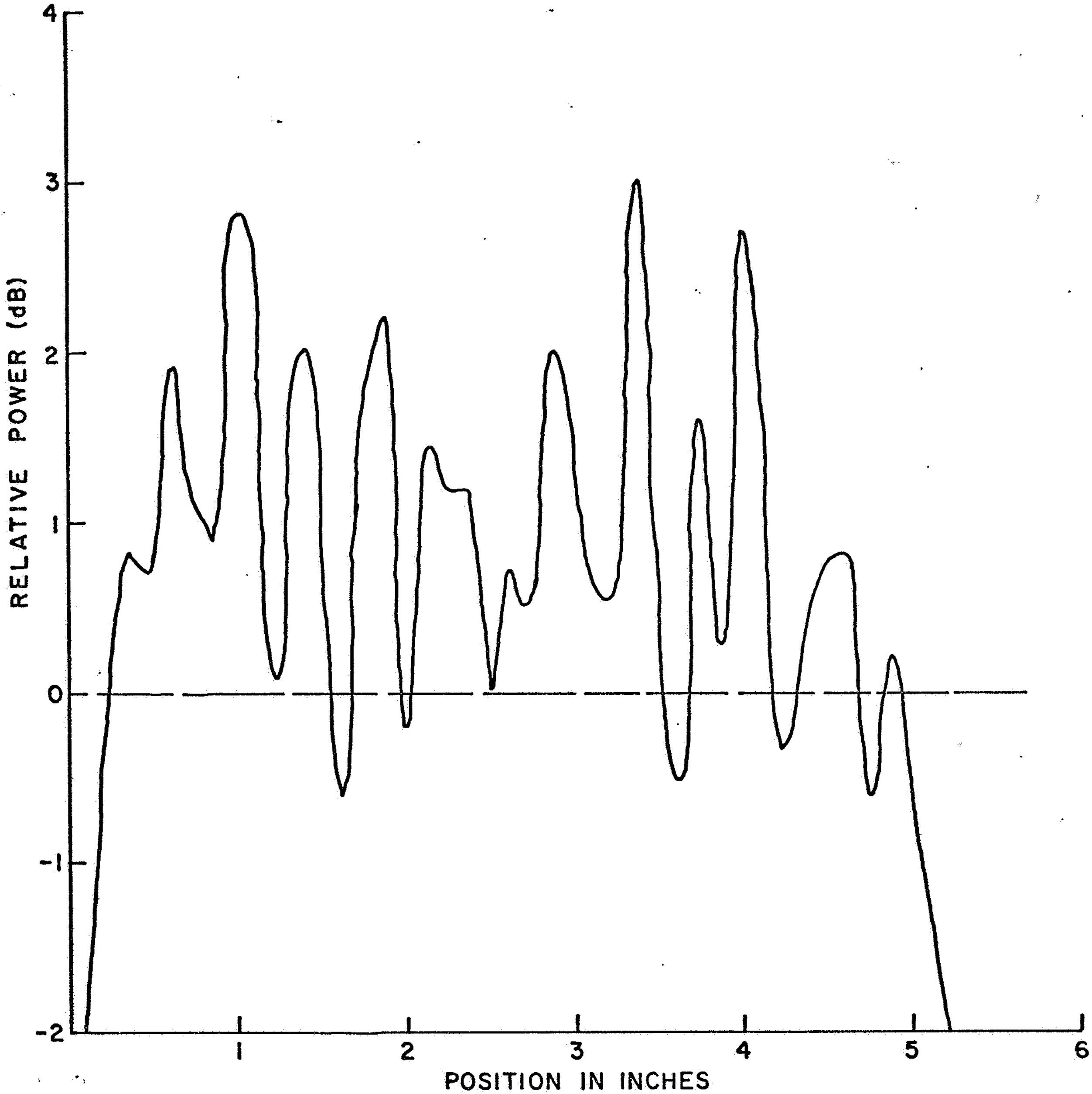

FIG. 7 -RELATIVE POWER vs POSITION (E-PLANE) WITH LENS IN APERTURE

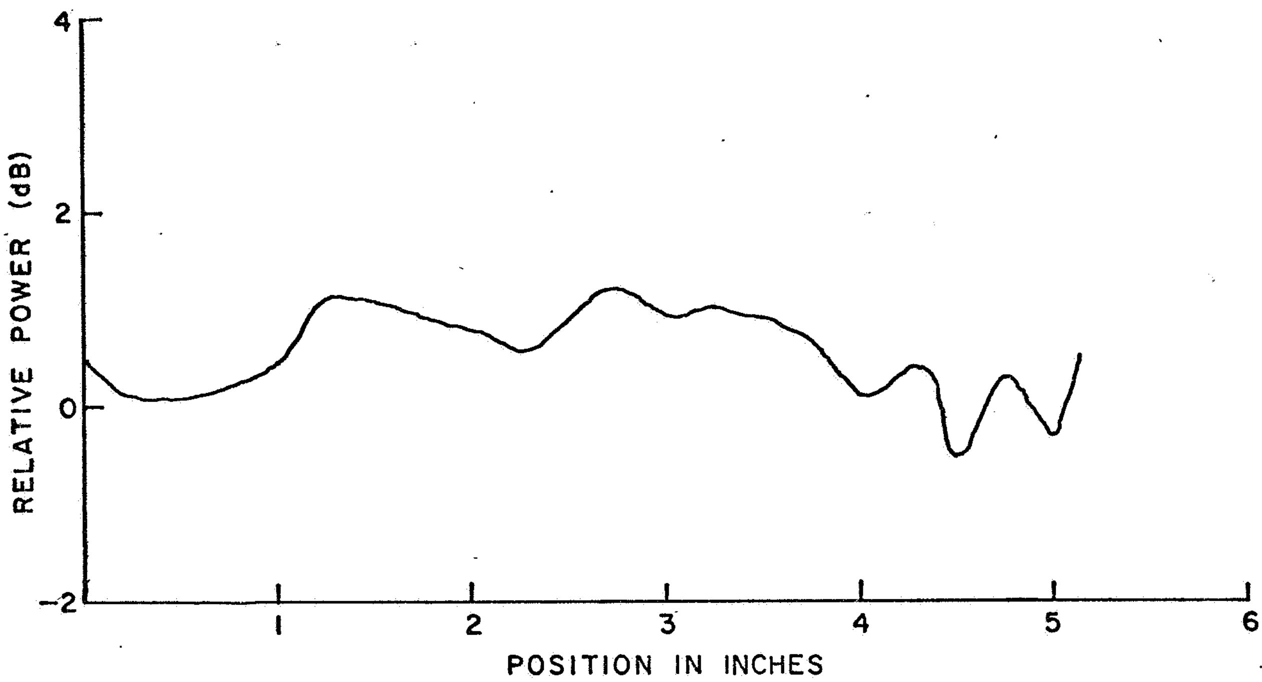

FIG. 8 -RELATIVE POWER vs POSITION (E-PLANE) WITHOUT LENS IN APERTURE

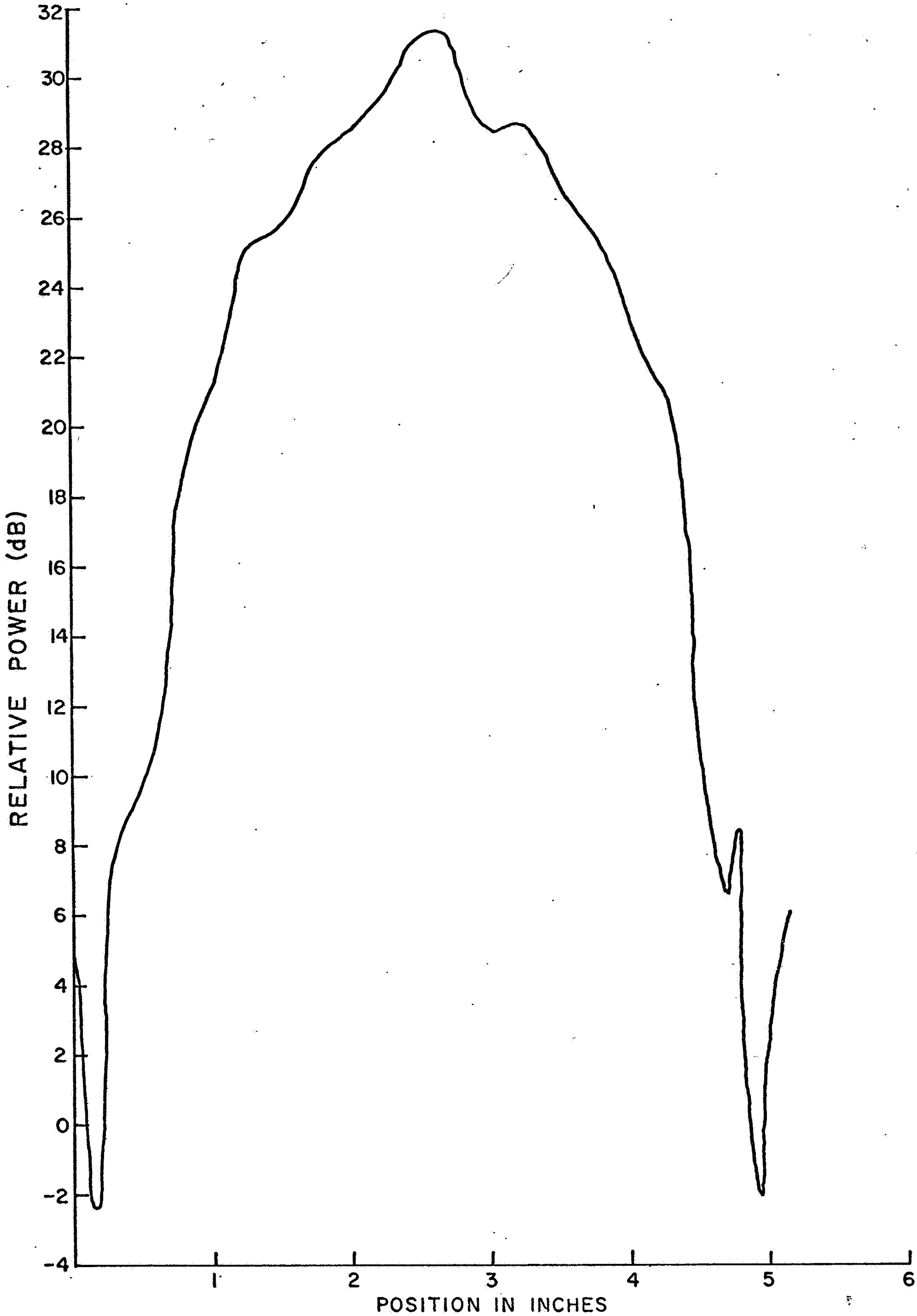

FIG. 9 -RELATIVE POWER vs POSITION (H-PLANE) WITH LENS IN APERTURE

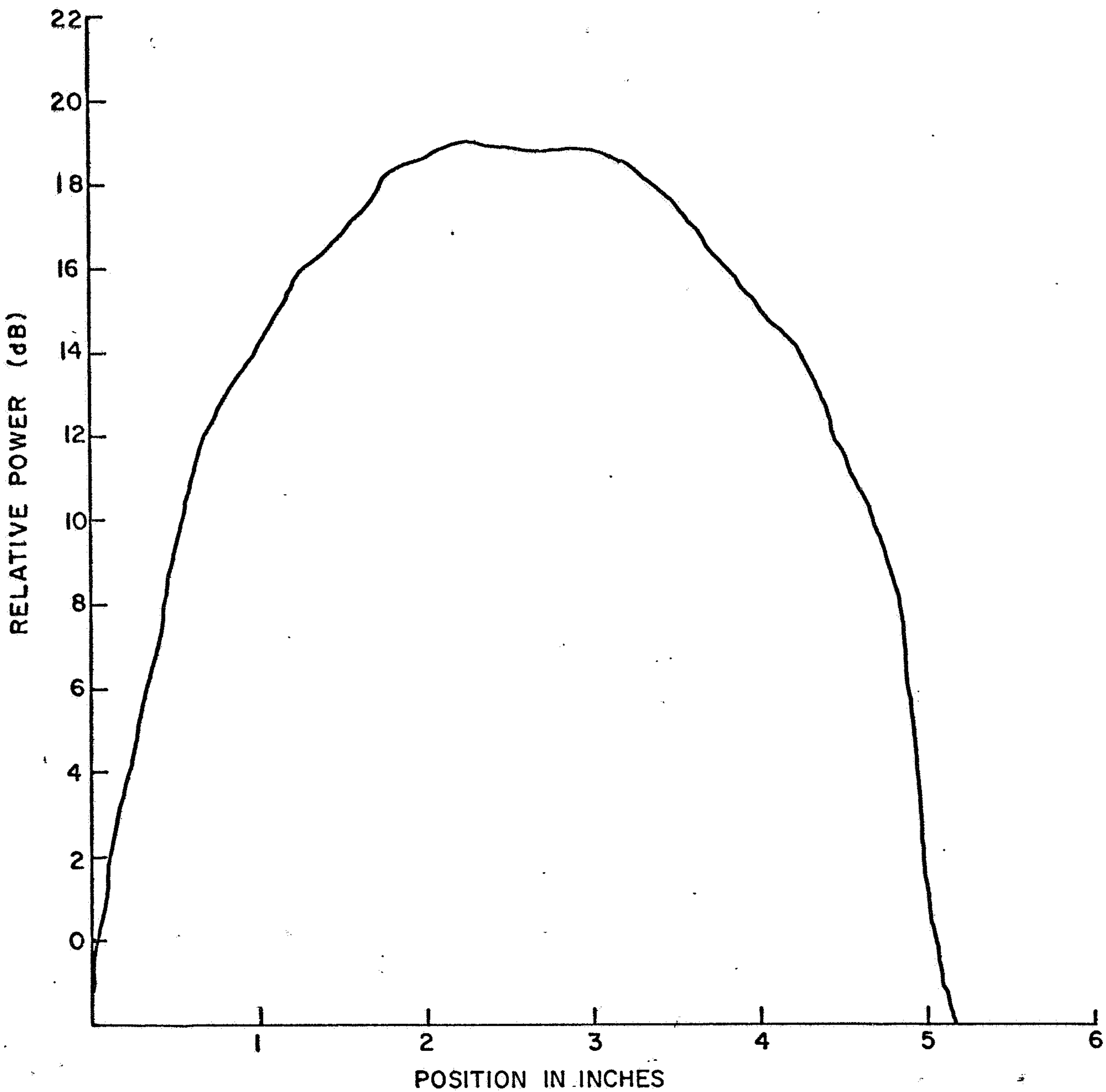

FIG. 10 - RELATIVE POWER vs POSITION (H-PLANE) WITHOUT LENS IN APERTURE

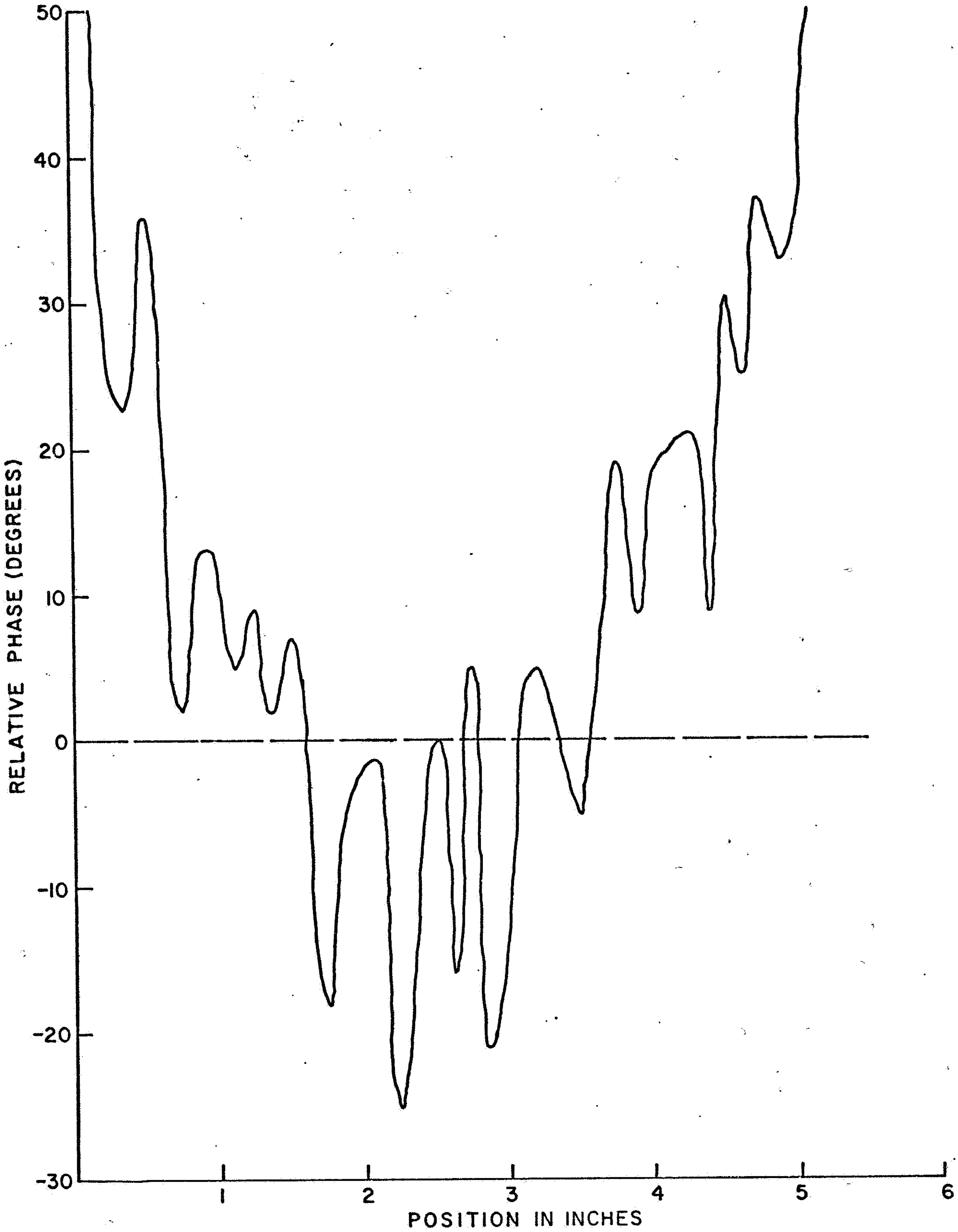

FIG. 11 -RELATIVE PHASE vs POSITION (E-PLANE) WITH LENS IN APERTURE

incidence) for parallel polarization. For perpendicular polarization the variation is from .231 at the center to .418 at the corner of the horn. However, since the impinging radiation is entirely parallel or perpendicular only on the center lines of the lens, the power reflection coefficient everyplace other than these center - lines is some combination of both of these polarizations. Hence, a complicated variation in power reflection coefficient results.

The effects of the mismatch (regular variations in power and therefore phase) can be reduced substantially by a matching structure on the surfaces of the lens. There are several methods available, but at this frequency only two seem practical. Both of these involve the use of a layer whose dielectric constant and thickness vary with angle of incidence to effect a quarter wave matching layer.

The first method uses an actual layer having a dielectric constant approximately equal to $\sqrt{\epsilon_1}$ where ϵ_1 is the dielectric constant of the lens. Since power reflection coefficient varies with angle of incidence, this method would seem to require a continuously varying dielectric constant which is not feasible. However, it has been shown[1] that a layer with a dielectric constant ϵ_m,

$$\epsilon_m = \sqrt{\epsilon_1}\ , \quad \epsilon_1 = \text{dielectric constant of lens,}$$

which is the value for normal incidence, is a good approximation at least for angles of incidence up to 50°. Then the only varying parameter is the thickness, t

$$t = \frac{\lambda_o}{4(\cos\theta)^{\frac{1}{2}} (\epsilon_1 - \sin^2\theta)^{\frac{1}{4}}}$$

where

θ = angle of incidence, i.e., angle between impinging ray and surface normal.

λ_o = free space wavelength.

The second method of producing a matching layer on the surface of the lens is by using an artificial dielectric. This is accomplished by cutting grooves in the lens itself. In order for the grooved "layer" to perform as a homogeneous medium, there should be at least ten trooves per wavelength. The dielectric constant is then varied by changing the depth and width of the grooves.

The depth of the groove is found by using the equation for thickness of the matching layer given above. The width of the groove is found from the relation

$$\frac{d}{\ell} = \frac{\cos\theta\,(\epsilon_1 - \sin^2\theta)^{\frac{1}{2}} - \cos^2\theta}{\epsilon_1 - 1}$$

where

$2d$ = width of the tongue

2ℓ = width of the groove plus the width of the tongue

ϵ_1 = dielectric constant of the lens

θ = angle between ray in air and the surface normal.

Since the artificial dielectric constant is a function of groove width and depth, this method utilizes a pseudo-continuous variation of dielectric constant and therefore is a more exact solution than the dielectric layer. However, this method involves cutting 160 grooves with extremely tight tolerance on each side of the lens and each one is different. Therefore, the former method will be tried and evaluated first.

3.2 Compensated Receiving Array

It has been stated in prior reports that, in order to achieve proper power distribution to the output array using the optical feed system, a compensating array of collecting horns will be needed. This entails either the use of asymmetric horns or waveguide bends with an offset in both the E-plane and the H-plane. Since the latter is the simpler approach, one such bend was made and tested during this reporting period.

Although the extent of the offsets of the bend are such that it represents a worst case for the present application, the results of the tests were encouraging. The piece had a VSWR of only 1.05 at the design frequency of 35 GHz and a maximum VSWR of 1.08 over the 33 GHz to 38 GHz band. These results show that this method is much more practical than the use of asymmetric horns. Pending the outcome of the lens and lens matching investigation, a set of the offset bends and the non-uniform array of collecting horns will be fabricated.

4. NEW TECHNOLOGY

During the period covered by this report, there have been no inventions, discoveries, or innovations which may be considered under the New Technology clause of the contract.

5. PROGRAM FOR THE NEXT INTERVAL

During the next quarter, work will be continued on the development and testing of the feasibility model of the antenna.

Efforts will be concentrated on producing an effective matching structure for the phase correcting lens. Analyses of the tests of the lensed horn feed system will be performed to determine the practicality of fabricating the non-uniform array of collecting horns.

It is expected that during the coming period, the first of the phase shifters will be delivered and preliminary tests of steering will be performed.

REFERENCES

1. E. M. T. Jones and S. B. Cohn, "Surface Matching of Dielectric Lenses", Journal of Applied Physics, 1955, Vol. 26, No. 4, p. 452.